THE APPLICATION OF THERMOMAGNETIC PROPERTIES OF Fe-Ni ALLOYS TO THE THERMAL HISTORY OF THE Y-74646 CHONDRITE

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Abstract: The thermomagnetic curves of Y-74646 chondrite have been measured. In order to analyzed these results, the magnetic properties of 29at% Ni-Fe alloys have been studied.

Comparing and analyzing the experimental results, the thermal history of Y-74646 chondrite is presumed as either of the following: (i) The chondrite has never been exposed to the temperature above 600°C. (ii) If it had been heated above 600°C, the chondrite was cooled below −193°C after heating.

1. Introduction

Recently, the petrological and chemical compositions of metals in Yamato-74646 (LL6) (denoted as Y-74646 in this paper) chondrite were studied by NAGAHARA (1979a, b). NAGATA and FUNAKI (1981) investigated the magnetic properties of antarctic stony meteorites, where the transition temperatures of the plessite phase and taenite phase in Y-74646 were discussed and the Fe-Ni metallic grains were estimated to have about 30 wt% Ni contents.

According to the EPMA study by FURUTA of the same Y-74646 chondrite that we have measured the thermomagnetic curves, the Ni contents are distributed in the range from 27.272 at% to 31.104 at% and the mean value is 28.504 at%.

In order to investigate the thermomagnetic properties of this chondrite, we prepared 29at%Ni-Fe alloys and measured the thermomagnetic behaviors and the Mössbauer effect, because the Ni content of this chondrite is 28.5 at% in the mean value by FURUTA. We tried to presume the thermal history of this chondrite by the application of the thermomagnetic properties of 29at%Ni-Fe alloys.

2. Experimental Results and Discussions

The Fe-Ni alloys were prepared by melting in an induction furnace. The purity of the elements was 99.9%. The samples of Fe-Ni alloys for the magnetic measurements and the Mössbauer effect were powdered by hand-grinder into about 200 mesh (grain size of 90–200μ in diameter).

The magnetic measurements were carried out by the quartz spring method in the external field of 3 kOe. The Mössbauer effect was measured by using the apparatus of Ranger controlled by the mini-computer at Shinshu University.

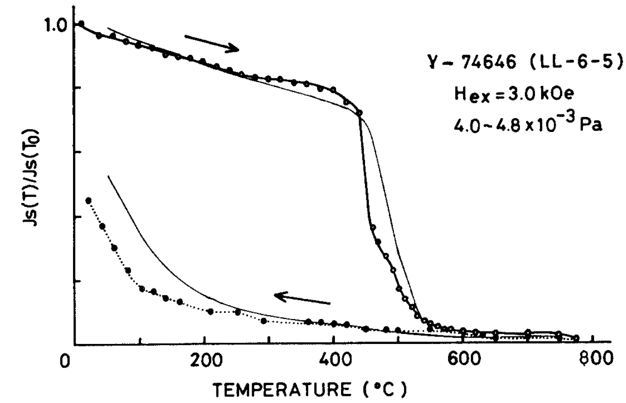

Fig. 1. *The first-run thermomagnetic curves of Y-74646 chondrite in the external field of 3.0 kOe. The thin solid lines are after FUNAKI.*

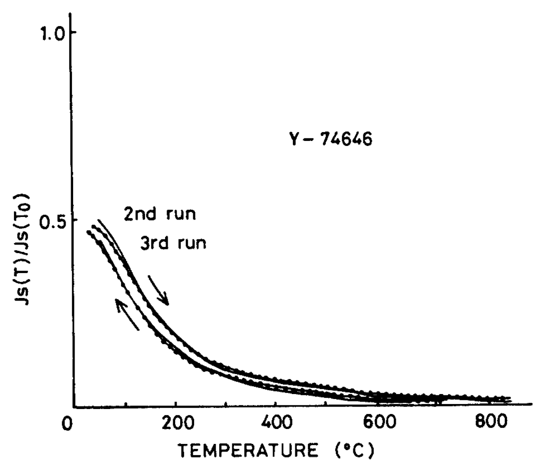

Fig. 2. *The 2nd and 3rd runs of the thermomagnetic curves of Y-74646 chondrite by FUNAKI in the external field of 5.0 kOe.*

The thermomagnetic curves of Y-74646 chondrite are shown in Fig. 1, where the anomalous thermal hysteresis was observed. The second and third runs of thermomagnetic curves of Y-74646 chondrite are shown in Fig. 2 where the third run was measured after two years of the second run measurement (the grain sizes of the magnetic samples are 80–100μ in diameter). The thermomagnetic curve of Y-74646 chondrite which was heated higher than 600°C had never been restored in a few years to that of the original state (before heat treatment). The cause of this phenomenon may be due to the diffusionless transformation from bcc to fcc phases. In order to confirm these results we investigated the magnetic properties of 29at%Ni-Fe alloys.

In Fig. 3 we show the thermomagnetic curves and the Mössbauer effect measurements of the powder samples of 29at%Ni-Fe alloys which are original (before heat treatment) and after annealing at 800°C for 3 hours in a vacuum of 10^{-3} pa. The thermomagnetic curves show the anomalous hysteresis similar to that of Y-74646 chondrite. The magnetization of this alloy is 95 emu/g at room temperature (T_0). The ratio of $J_s^c(T_0)/J_s^h(T_0)$ is obtained to be 0.24 at T_0, where $J_s^c(T)$ and $J_s^h(T)$ are the

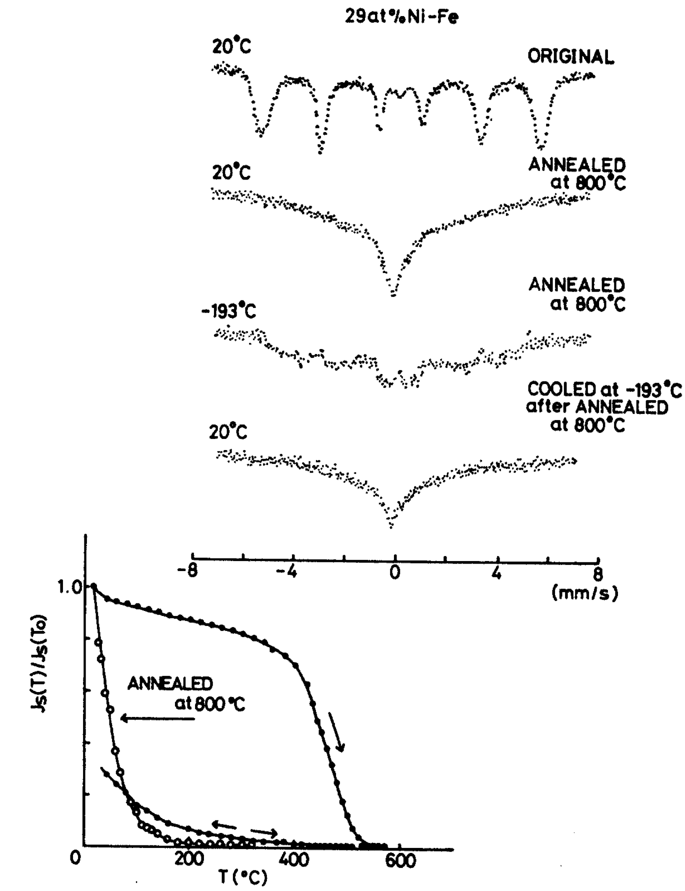

Fig. 3. The thermomagnetic curves and Mössbauer spectra of the powder samples of 29at%Ni-Fe alloys. Closed circles show the thermomagnetic curves of the original samples and open circles show that of the sample annealed at 800°C for 3 hours, in the external field of 3.0 kOe.

magnetizations of cooling and heating processes, respectively.

If we assume the value of $J_s^c(T_0)$ to be due to the fcc phase, since in the X-ray analysis the bcc phase disappears after heating, the fcc phase content (x) in the original sample is estimated as follows:

$$95 = 197.6(1-x) + 22.8x, \tag{1}$$

where the value of 197.6 (emu/g) is the magnetization of the bcc phase by CRANGLE and HALLAM (1963), CRANGLE and GOODMAN (1971) and 22.8 (emu/g)=95 (emu/g)$\times$ 0.24. The fcc phase content is obtained to be 58% by eq. (1) and in good agreement with that estimated by the Mössbauer effect measurements (61%).

The Mössbauer spectra of Fig. 3 show that (i) two phases (bcc and fcc) coexist in the original smaple, (ii) the bcc phase disappears after annealing and the Fe moment of the fcc phase is very small at T_0 (less than $0.3\mu_B$), (iii) the Fe moment at -193°C is about $1.8\mu_B$, and (iv) the annealed sample shows the very small magnetization at T_0 after cooling.

On the other hand, 29at%Ni-Fe alloy cooled slowly from the melting point to T_0 for 4 hours contains 80% fcc phase.

In Fig. 4 we show the thermomagnetic curves of the powder samples (grain sizes of 90–200μ in diameter) of alloys after two kinds of heat treatments: one is the block ($\sim$0.4 cm^3 bulk) annealing at 800°C for 3 hours in vacuum of 10^{-3} Pa, and the other is the powder annealing under the same condition as in the case of the block annealing.

The thermomagnetic curve of the bulk sample annealed at 800°C was coincident with that of the powder annealed sample in Fig. 4.

The experimental results are listed in Table 1. It is obvious from Table 1 that (i) the methods of the sample preparations influence severely on the thermomagnetic curves and (ii) the thermomagnetic curves of the powder samples annealed higher than 600°C were reversible (see (d)–(g) of Table 1).

The strain of the sample caused by the hand-grinder may be the origin of the irreversible behavior of the thermomagnetic curve. The details of the effect by the strain will be discussed elsewhere.

From the above-mentioned results and discussions we can presume the thermal

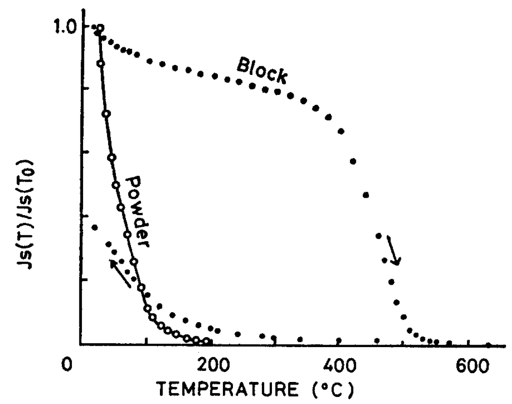

Fig. 4. The thermomagnetic curves of the powder samples of 29at%Ni-Fe alloys after block annealing (closed circles) and powder annealing (open circles), in the external field of 3.0 kOe.

Table 1. The experimental results of 29at%Ni-Fe alloys.

Shape of sample	Heat treatment	Phase	Thermomagnetic curve
Powder (ground after heat treatment)	(a) Quickly cooling	$\sim$60% fcc+$\sim$40% bcc	Irreversible
	(b) Slowly cooling	$\sim$80% fcc+$\sim$20% bcc	Irreversible
	(c) Block annealing of samples (a) and (b) at 800°C for 3 hr		Irreversible
Powder	(d) Powder annealing at 800°C, for 3 hr	fcc	Reversible
	(e) Powder cooling from 600°C	fcc	Reversible
	(f) Powder cooling from melting point	fcc	Reversible
	(g) Powder cooling at −193°C of sample (d)	fcc	Reversible
Block	(h) Block annealing at 800°C, for 3 hr	fcc	Reversible

history of Y-74646 chondrite as either of the following:
(1) The chondrite has never been exposed to the temperature above 600°C in the small particle size. If it was exposed above 600°C, the first run of the thermomagnetic curve has no thermal hysteresis (see (d)–(g) of Table 1).
(2) If it had been heated above 600°C, the chondrite was cooled to the temperature below −193°C after heating, because the powder sample heated above 600°C shows the reversible thermomagnetic curve (see Table 1).

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